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Delayed Detonation After Projectile Impact

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13. ABSTRACT *(Maximum 200 words)*

In an effort to understand the mechanisms which cause munitions impacted by fragments to detonate, we conducted a test series in which we impacted 105-mm HEP warheads (Comp B loaded) by flat-faced cylindrical steel projectiles. The velocity of the projectile was varied in order to determine a 50% velocity for detonation. We instrumented our test with an external blast pressure probe and an internal carbon resistor gage so that we could discriminate between detonations and low-order explosive reactions. In addition, witness plates were used to record the fragmentation pattern of the 105-mm rounds. We have observed three broad categories of explosive reaction which are a function of the velocity of the impacting projectile: (1) prompt detonation at fragment velocities above 1,150 m/s (3,773 ft/s), (2) delayed detonation at fragment velocities around 1,150–900 m/s (3,609–2,952 ft/s), and (3) no detonation at fragment velocities below 900 m/s (2,952 ft/s). For any given fragment velocity, there was a wide variability in the measured delay time for explosive reaction. We attribute this variability to possible differences in hit location of the flat-nosed projectile on the cylindrical surface of the warhead, which would cause differences between the impact shock loadings even though the fragment velocity was the same.

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1. INTRODUCTION

The response of explosive-filled munitions to fragment attack is important both from a vulnerability aspect and also because a better understanding of the parameters that influence explosive reaction could lead to improved munitions. The prompt detonation response of bare explosive to fragment impact is well described by the critical energy concept (Gittings 1965; Walker 1969) and various refinements to this concept (Bahl, Vantine, and Weingart 1981). When the explosive is confined (e.g., in a munition), other initiation mechanisms can become important so that a reacting explosive can eventually build to a detonation, given the additional time which confinement provides. These "nonprompt" detonations can require as much as 100 μs in our experiments whereas prompt detonations obtained from wedge test data (Gibbs and Popolato 1980; Dobratz and Crawford 1985) appear to occur within 10 μs or less.

2. EXPERIMENTAL PROCEDURE

In order to investigate delayed detonations, we used the experimental arrangement shown in Figure 1. A Comp B-filled 105-mm HEP-T warhead was placed about 127 mm (5.00 in) above a steel armor witness plate supported by a heavy armor table. A 1-in smoothbore powder gun accelerated a 19-mm-diameter (0.75 in) x 38-mm-long (1.5 in) steel projectile weighing 76 g (0.17 lb); the gun was aimed so that the projectile would impact the warhead on its cylindrical surface at the midline and centered on the round. The flat-faced steel projectile impacted the round at a normal obliquity. Although the yaw was not measured in this test series, we had previously performed similar firings using this projectile and the yaw appeared to be reproducible within ± 5 degrees. The projectile velocity was determined using velocity screens, and the initial impact on the warhead was obtained from a shorting screen taped to the body of the warhead. This screen provided the zero reference time for both the carbon resistor gauge (McAfee 1989; Ginsberg 1991) and the free-field blast probe. The actual hit point of the projectile on the warhead varied within approximately 9.5 mm (0.375 in) of the aim point.

We used a carbon resistor gauge in order to determine the time after impact that a reaction wave or a detonation reached the base of the round where the gauge was located. The distance between the impact point and the gauge was 145 mm (5.71 in), as shown in Figure 2. The carbon resistor gauge configuration that we used in these tests differed from that described in McAfee (1989) and Ginsberg (1991). Our gauge consisted of a 1/8-W, 470-ohm resistor made by the Allen Bradley Company. We epoxied it within a polyethylene cylinder so that there was a 3.2-mm (0.125-in) layer of polyethylene between the gauge

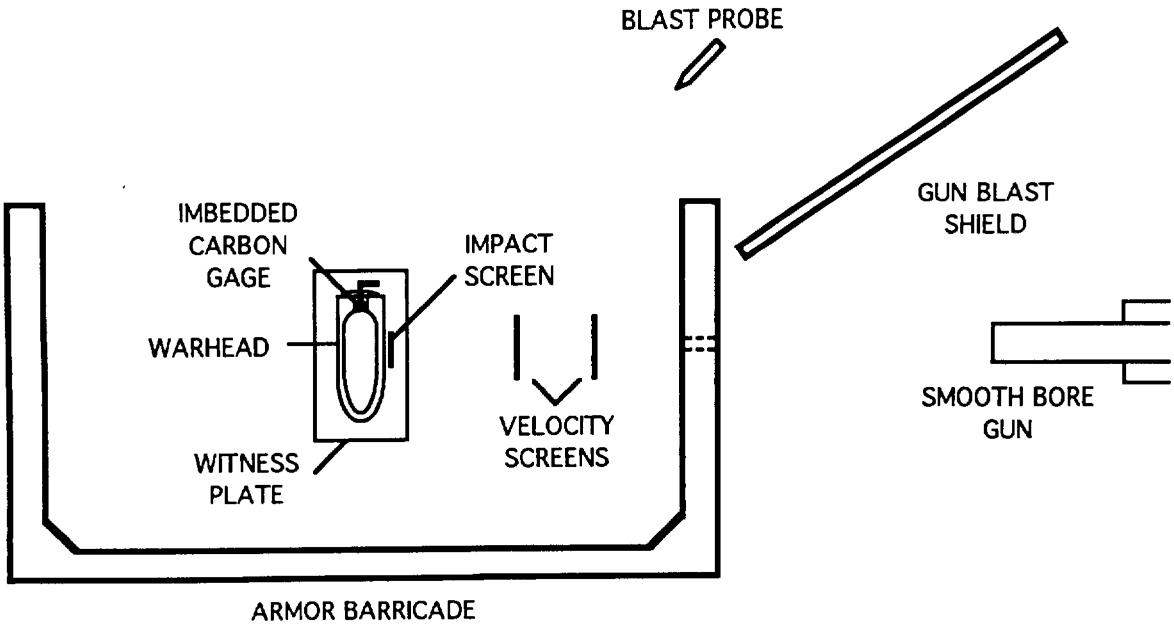

Figure 1. Experimental arrangement (overhead view).

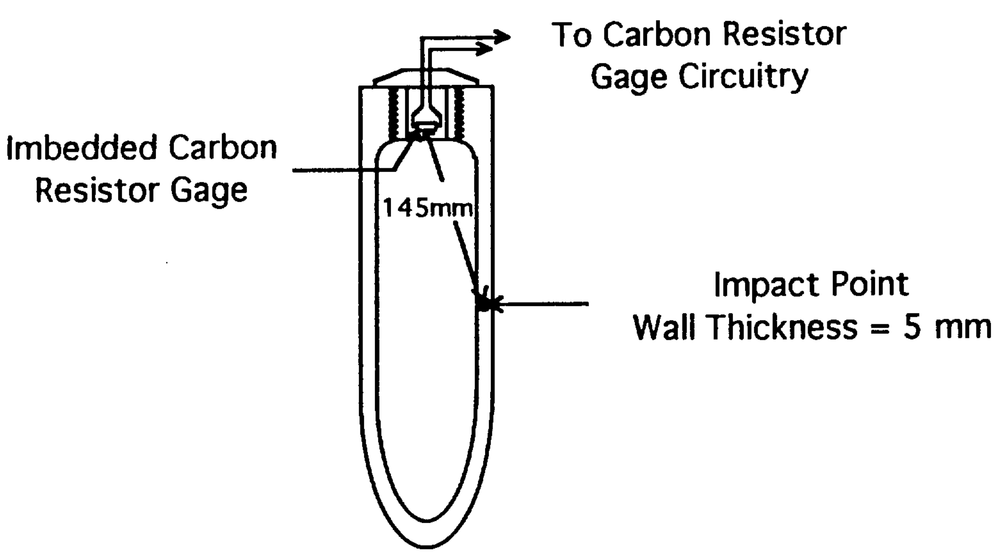

Figure 2. Cross-section view of a carbon resistor gauge in a 105-mm HEP-T warhead.

and the explosive fill when the gauge was inserted into the warhead, as shown in Figure 2. The encapsulated gauge was held in a machined cavity in the base plug of the warhead, and the lead wires came out through a small diameter hole drilled through the base plug. We basically followed the procedures described in McAfee (1989) for the gauge circuitry and analysis of the gauge records.

We also used a free-field blast pressure probe in order to measure the side-on pressure associated with explosive reaction of the warhead. The probe was positioned 4.6 m (15 ft) from the impact point in all these tests. In addition, we used a steel armor witness plate as an indicator of warhead detonation.

3. RESULTS

Our experimental results are listed in Table 1. The carbon gauge arrival time is the time after impact that the gauge responds to an explosive reaction, whether that reaction is a detonation or a milder event which may increase pressure at a much lower rate. The blast probe gives a good far field indication of the level of explosive reaction.

4. DISCUSSION

We have plotted our results for fragment velocity vs. time after impact in Figure 3. We have observed several modes of warhead response to fragment impact:

1. Nondetonation, generally characterized by recovered explosive or possibly large case fragments (large in comparison to fragments associated with detonation)

2. Detonation, both prompt and nonprompt, which produce characteristic high pressure and small fragment size

3. Nose-only detonations, where apparently only the nose section of the warhead detonated generating a typical fragmentation pattern in that region only and no fragmentation pattern in the remainder of the round. The blast pressures associated with these nose-only detonations appeared to be even higher than those measured for the detonation mode.

Table 1. Delayed Detonation Test Results

Shot No.	Projectile Velocity (m/s)	(ft/s)	Carbon Gauge Arrival Time (μs)	Blast Probe Pressure (kPa)	(psi)	Blast Probe Arrival Time (ms)	Reaction Level
1	907	(2,975)	–	76.5	(11.1)	6.2	nose detonation, no HE recovered, large case frags
2	952	(3,122)	132	11.7	(1.7)	10.8	explosive reaction, large pieces of HE recovered
3	1,017	(3,338)	63	79.9	(11.6)	6.1	nose detonation, no HE recovered, large case frags
4	1,104	(3,621)	54	59.9	(8.7)	7.4	detonation
5	1,077	(3,533)	62	64.1	(9.3)	7.1	detonation
6	901	(2,955)	68	14.5	(2.1)	10.4	explosive reaction, melted and powdered HE recovered
7	782	(2,565)	71	14.5	(2.1)	10.5	explosive reaction, HE recovered
8	1,673	(5,489)	22	74.5	(10.8)	7.2	detonation
9	1,385	(4,543)	23	49.6	(7.2)	7.3	detonation
10	1,091	(3,578)	88	23.4	(3.4)	9.0	explosive reaction, no HE recovered, small case frags
11	1,183	(3,881)	62	52.4	(7.6)	7.3	detonation
12	1,238	(4,063)	27	50.3	(7.3)	7.3	detonation
13	1,208	(3,963)	26	56.5	(8.2)	7.5	detonation
14	1,155	(3,789)	41	55.8	(8.1)	7.6	detonation
15	1,173	(3,849)	38	48.3	(7.0)	6.9	detonation
16	1,148	(3,765)	72	54.5	(7.9)	6.9	detonation
17	1,122	(3,682)	66	60.0	(8.7)	6.9	detonation
18	1,106	(3,628)	110	71.7	(10.4)	6.5	nose detonation, no HE recovered, small case frags
19	1,146	(3,761)	31	57.9	(8.4)	7.1	detonation

Table 1. Delayed Detonation Test Results (Continued)

Shot No.	Projectile Velocity (m/s)	(ft/s)	Carbon Gauge Arrival Time (μs)	Blast Probe Pressure (kPa)	(psi)	Blast Probe Arrival Time (ms)	Reaction Level
20	1,159	(3,802)	63	62.1	(9.0)	7.2	detonation
21	1,291	(4,234)	35	51.7	(7.5)	7.2	detonation
22	1,243	(4,077)	52	64.1	(9.3)	7.2	detonation
23	1,398	(4,585)	56	54.5	(7.9)	7.3	detonation
24	1,418	(4,651)	39	56.5	(8.2)	7.2	detonation
25	1,439	(4,722)	26	56.5	(8.2)	7.4	detonation
26	1,457	(4,779)	24	54.5	(7.9)	7.4	detonation

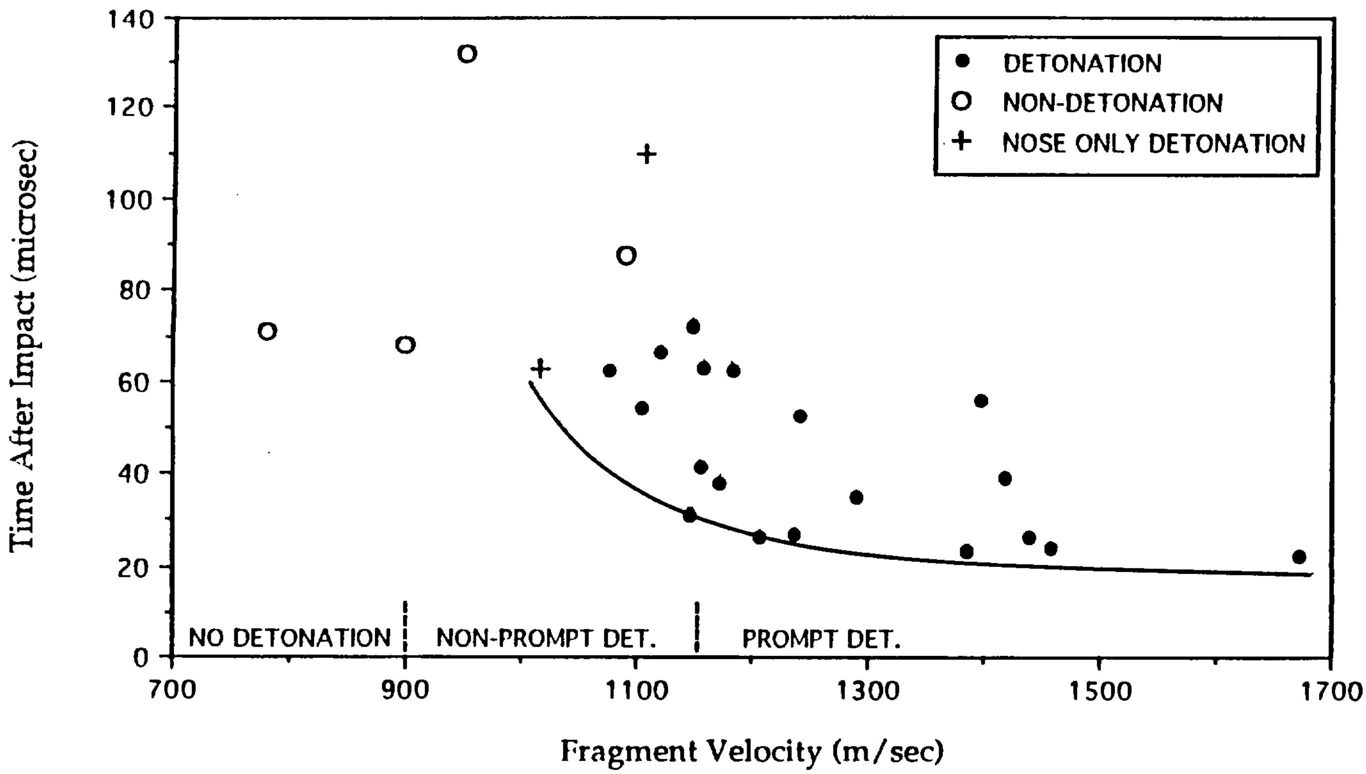

Figure 3. Fragment velocity vs. the time after impact that the carbon resistor gauge detects a signal.

In Figure 3, there is a wide variability in the explosive response time for a given fragment velocity. We attribute this to differences in the impact shock loading, caused by variability in the hit point and the projectile yaw. Although we have not done a detailed analysis of the impact shock loading, it appears reasonable to assume that if the hit point occurs off the midline of the cylindrical warhead the severity of the impact shock would be decreased and if the fragment were appropriately yawed there would be an additional degradation of the impact shock. With this assumption, we have drawn a boundary curve through our experimental points. This curve relates the time after impact that a reaction wave arrives at the gauge to the velocity of a nonyawed fragment impacting the cylindrical surface at the center of its midline. The minimum response time of 22 μs for a fragment velocity of 1,673 m/s (5,489 ft/s) corresponds to an immediate detonation of the warhead upon fragment impact. At about 1,150 m/s (3,773 ft/s), the response time is around 31 μs corresponding to a detonation delay of about 9 μs; we interpret this to be the velocity at which an idealized impact would cause a nonprompt detonation response of the warhead.

There are two nose-only detonations shown in Figure 3. A third nose-only detonation (without a carbon gauge record) is listed as Shot No. 1 in Table 1. The impact velocity for this shot was very low, 907 m/s (2,980 ft/s). We estimate that the nondetonation response of the warhead occurs at an impact velocity of around 900 m/s (2,953 ft/s), as indicated in Figure 3. The nose-only detonation represents a very marginal detonation since only the nose portion of the warhead appears to detonate, yet the blast probe measurements (peak pressure and shock arrival time) give values indicative of a response stronger than a standard detonation in which the entire warhead detonates. The reason for this anomalous behavior is unknown. Table 2 correlates explosive response and blast probe measurements.

Table 2. A Correlation of Explosive Response and Blast Probe Measurements

Explosive Response	Averaged Peak Shock Pressure (kPa)	(psi)	Averaged Shock Arrival Time (ms)
Nondetonation	16.0	(2.32)	10.2
Detonation	60.2	(8.73)	7.2
Nose-Only Detonation	76.0	(11.0)	6.3

In shots where the warhead detonated, the carbon gauge records gave good arrival time data and wide variability in the peak pressure. This is shown in Figure 4 for Shot Nos. 17 and 26. For the nose-only detonations, the carbon gauge records in Figure 5 indicate the same trend in level of explosive reaction as shown in Table 1 for Shot Nos. 3 and 18. In a similar manner, the carbon gauge records for nondetonations show the same trend; higher pressures correspond to a higher level of explosive reaction as evidenced by the smaller size of the recovered fragments. Figure 6 shows two carbon gauge records for nondetonation, Shot Nos. 7 and 10, which can be compared to the reaction level in Table 1. Also, in these shots, the pressure and the pressurization rate both increase as the velocity of the impacting fragment increases. We do not have enough carbon gauge data to say if this is generally true; in addition, the occurrence of "non-ideal" impacts may obscure any relationship between the fragment velocity and the carbon gauge data. All the carbon gauge records are eventually perturbed as the gauge begins to short out or break.

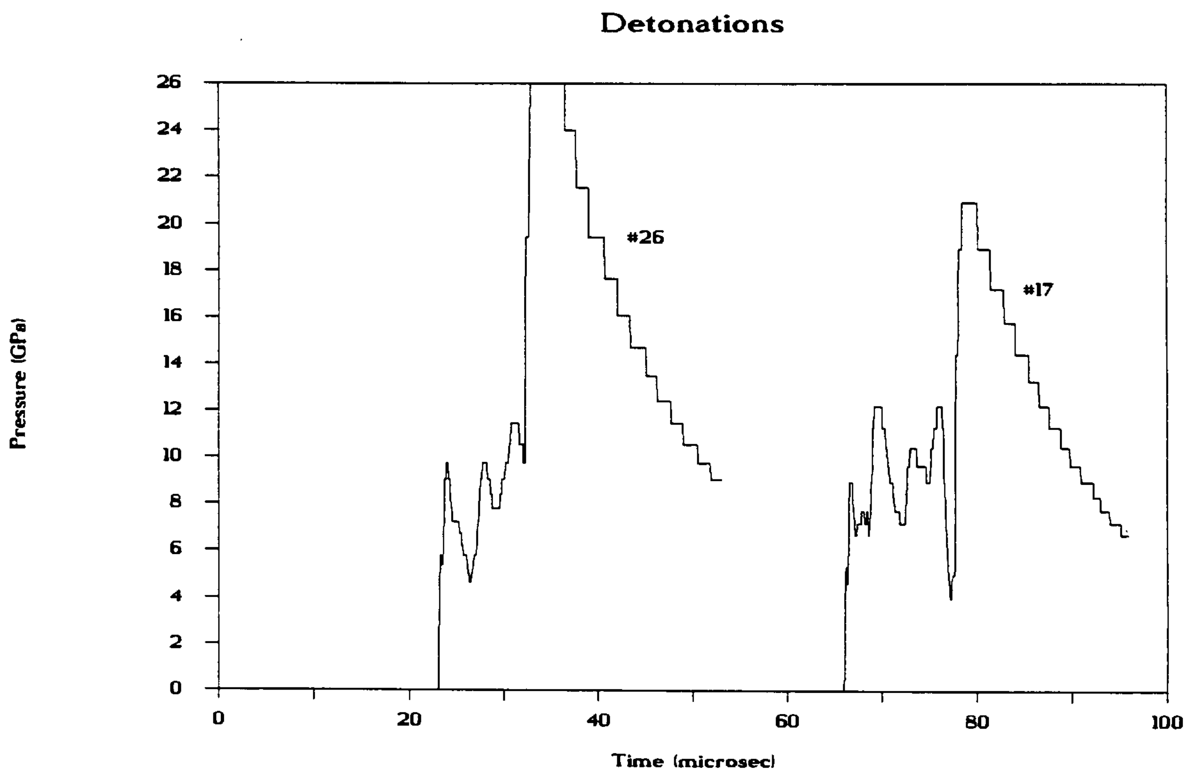

Figure 4. Carbon resistor gauge records for detonation.

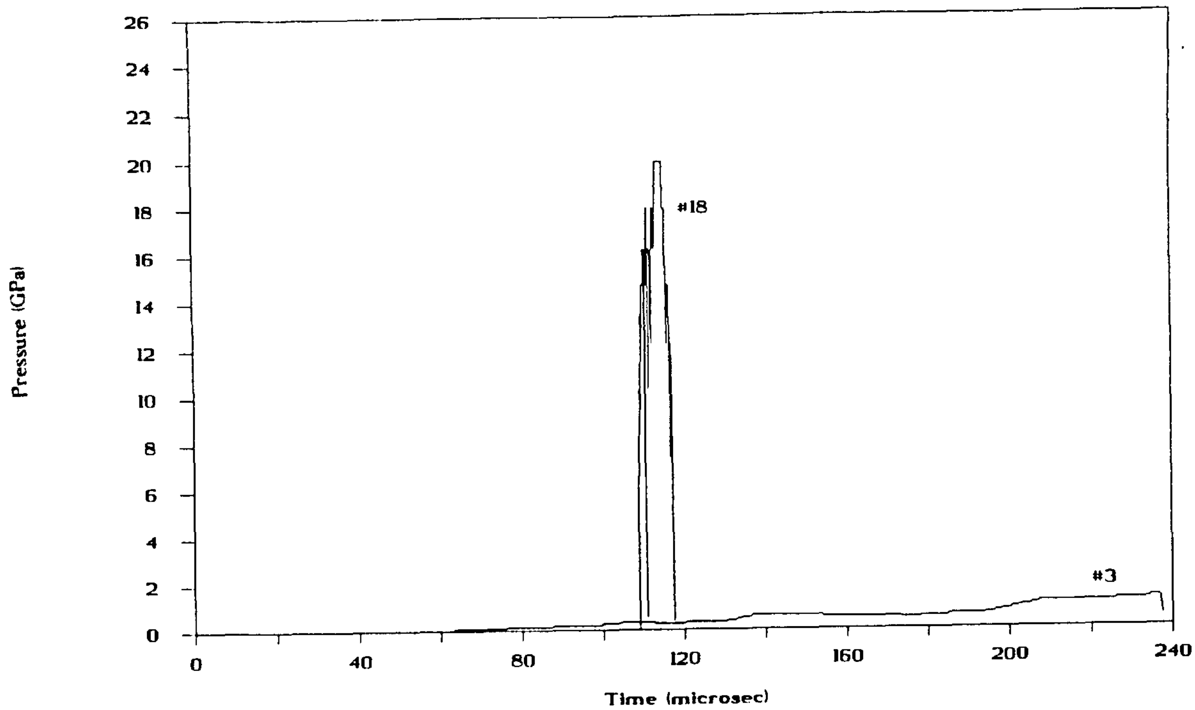

Figure 5. <u>Carbon resistor gauge records for nose-only detonations.</u>

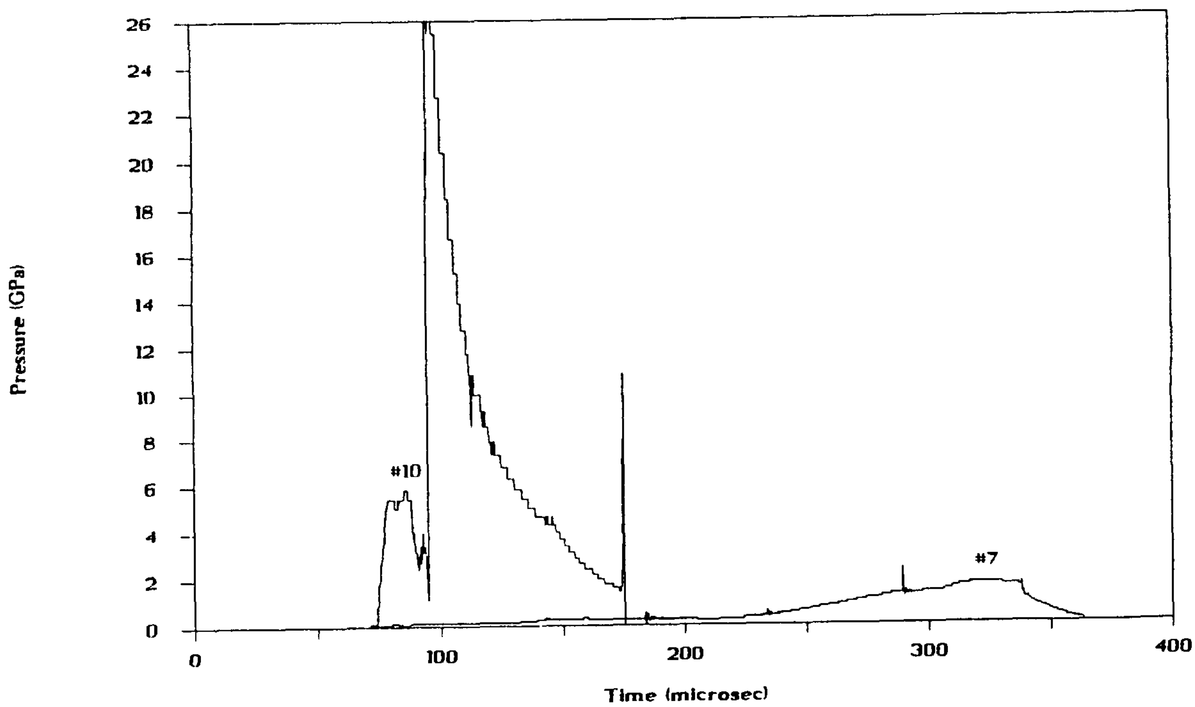

Figure 6. <u>Carbon resistor gauge records for nondetonations.</u>

5. CONCLUSIONS

Although the variability in our data necessarily make our conclusions to be somewhat qualitative, they may serve as a guide for future investigations into nonprompt detonation phenomena.

- For the idealized lower boundary data curve (Figure 3), nonprompt detonations start at an impact velocity of about 1,150 m/s (3,773 ft/s). In practice, we observe nonprompt detonations at higher velocities also, but we attribute this to nonideal impact (due to variability in fragment yaw and hit location).

- These nonprompt detonations occur as much as 80 μs later than a prompt detonation.

- We estimate that the idealized nondetonation response occurs around an impact velocity of 900 m/s (2,953 ft/s) and below.

- The concavity of the inner steel surface of the warhead in the nose region may promote nose-only detonation by focusing internally reflected shock waves.

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